

**Charnock Initial Regional
Response Activities (CIRRA)**

**TASK 5
TREATMENT TECHNOLOGY PERFORMANCE REPORT
Charnock Sub-Basin
Los Angeles, California**

**VOLUME I
REPORT and APPENDICES A thru I**

submitted to:

**California Regional Water Quality Control Board
Los Angeles Region**

and

**U.S. Environmental Protection Agency
Region IX**

on behalf of:

**Shell Oil Company
Shell Oil Products Company
Equilon Enterprises LLC**

prepared by:

**Kennedy/Jenks Consultants
Irvine, California
K/J 004028.00**

1 October 2000

**Kennedy/Jenks Consultants
Engineers & Scientists**

**Charnock Initial Regional
Response Activities (CIRRA)**

**TASK 5
TREATMENT TECHNOLOGY PERFORMANCE REPORT
Charnock Sub-Basin
Los Angeles, California**

**VOLUME I
REPORT and APPENDICES A thru I**

submitted to:

**California Regional Water Quality Control Board
Los Angeles Region**

and

**U.S. Environmental Protection Agency
Region IX**

on behalf of:

**Shell Oil Company
Shell Oil Products Company
Equilon Enterprises LLC**

prepared by:

**Kennedy/Jenks Consultants
Irvine, California
K/J 004028.00**

1 October 2000

**Kennedy/Jenks Consultants
Engineers & Scientists**

Charnock Initial Regional Response Activities (CIRRA)

TASK 5 TREATMENT TECHNOLOGY PERFORMANCE REPORT Charnock Sub-Basin Los Angeles, California

1 October 2000

submitted to:

**California Regional Water Quality Control Board
Los Angeles Region**

and

**U.S. Environmental Protection Agency
Region IX**

on behalf of:

**Shell Oil Company
Shell Oil Products Company
Equilon Enterprises LLC**

prepared by:

KENNEDY/JENKS CONSULTANTS
2151 Michelson Drive, Suite 100
Irvine, California 92612-1311

K/J 004028.00

Joseph A. Drago, P.E. (Civil), Ph.D.
Senior Environmental Engineer

Craig E. Dial, P.E. (Chemical)
Project Manager

Kennedy/Jenks Consultants
Engineers & Scientists

TABLE OF CONTENTS

SECTION

PAGE

VOLUME I

1	INTRODUCTION.....	1
1.1	Influent Water Characterization	1
1.2	Treatment Goal Basis	1
1.2.1	Drinking Water	2
1.2.2	Discharge to NPDES Connector	2
1.3	Report Organization	2
2	LITERATURE REVIEW	3
2.1	Scope of Review.....	3
2.1.1	Sorption Technologies	4
2.1.2	Air Stripping Technologies	4
2.1.3	Advanced Oxidation Technologies	4
2.1.4	Biological Technologies	4
2.1.5	Membrane Technologies.....	4
2.1.6	Electron Beam Technology	4
2.1.7	Blending.....	4
2.2	Sorption Technologies.....	4
2.2.1	Sorption of MtBE to GAC	5
2.2.1.1	GAC Treatment of MtBE for Drinking Water Applications	5
2.2.1.2	GAC Treatment for Remediation	6
2.2.1.3	Effect of Co-Contaminants on GAC Treatment of MtBE	6
2.2.1.4	Impact of GAC Sorption on Treated Water Quality	6
2.2.1.5	Cost	6
2.2.2	Resin Sorption for MtBE Removal.....	7
2.2.2.1	Synthetic Resins for Drinking Water Treatment of MtBE	7
2.2.2.2	Pilot Studies for Remediation of MtBE Using Resins.....	7
2.2.2.3	Impact of Water Constituents on Resin Sorption	7
2.2.3	Resin-Enhanced Sorbents	8
2.2.4	Resin Regeneration	8
2.2.4.1	Steam Regeneration	8
2.2.4.2	Solvent Regeneration.....	8
2.2.4.3	Microwave Regeneration.....	9
2.2.4.4	Impact of Resin Treatment on Treated Water Quality.....	9
2.2.4.5	Cost	9
2.3	Air Stripping.....	9
2.3.1	Packed Tower Aeration.....	10
2.3.1.1	Treatment of MtBE for Drinking Water Using Packed Towers	10
2.3.1.2	Impact of Water Quality Characteristics on MtBE Removal	10
2.3.1.3	Impact of MtBE Treatment by Air Stripping on Water Quality.....	10
2.3.1.4	Cost	11
2.3.2	Tray Stripping	11

TABLE OF CONTENTS (continued)

<u>SECTION</u>	<u>PAGE</u>
2.3.2.1 Treatment of MtBE for Drinking Water Using Tray Stripping.....	11
2.3.2.2 Impact of Water Quality Characteristics on MtBE Removal	11
2.3.2.3 Impact of MtBE Treatment by Tray Aeration on Water Quality.....	11
2.3.2.4 Cost	11
2.3.3 Heated Water Stripping.....	11
2.3.3.1 Heated Water Stripping for MtBE	11
2.3.3.2 Impact of Water Quality Characteristics on MtBE Removal by Heated Water Stripping	12
2.3.3.3 Impact of MtBE Treatment by Heated Water Stripping on Water Quality	12
2.3.4 Heated Water – Vacuum Stripping Process	12
2.3.4.1 Heated Water – Vacuum Stripping for MtBE Treatment	12
2.3.4.2 Impact of Water Quality Characteristics on Heated Water – Vacuum Stripping.....	12
2.3.4.3 Impact of MtBE Treatment by Heated Water - Vacuum Stripping on Water Quality	12
2.3.5 Off-Gas Treatment During Air Stripping	13
2.3.6 Vapor Phase GAC Adsorption.....	13
2.3.6.1 Vapor Phase GAC for Off-Gas MtBE treatment.....	13
2.3.6.2 Cost	13
2.3.7 Thermal and Catalytic Oxidation	13
2.3.7.1 Thermal or Catalytic Oxidizers for Off-Gas MtBE Treatment.....	14
2.3.7.2 Cost	14
2.3.8 Biological Off-Gas Treatment.....	14
2.3.8.1 Bio-Filter for Off-Gas MtBE Treatment	14
2.3.8.2 Cost	14
2.3.9 Vapor Concentrator.....	14
2.4 Advanced Oxidation Technologies	15
2.4.1 Hydrogen Peroxide/Ozone (H ₂ O ₂ /O ₃).....	15
2.4.1.1 Application of H ₂ O ₂ /O ₃ Treatment for Drinking Water Systems	16
2.4.1.2 H ₂ O ₂ /O ₃ Systems for Remediation Applications	16
2.4.1.3 Effect of Water Quality Characteristics on H ₂ O ₂ /O ₃ Treatment.....	17
2.4.1.4 Impact of H ₂ O ₂ /O ₃ Processes on Treated Water Quality.....	17
2.4.1.5 Cost of Treatment	17
2.4.2 UV/O ₃ Systems	17
2.4.2.1 UV/O ₃ Systems for MtBE Treatment in Drinking Water Systems	18
2.4.2.2 UV/O ₃ Systems for MtBE Remediation:.....	18

TABLE OF CONTENTS (continued)

<u>SECTION</u>	<u>PAGE</u>
2.4.2.3	Impact of Water Quality Characteristics and Co-contaminants on UV/O ₃ Treatment..... 18
2.4.2.4	Water Quality Issues 18
2.4.2.5	Cost 18
2.4.3	UV/H ₂ O ₂ Systems 18
2.4.3.1	UV/H ₂ O ₂ Systems for MtBE Treatment..... 19
2.4.3.2	Impact of Water Quality Characteristics on UV/H ₂ O ₂ Treatment..... 20
2.4.3.3	Impact on Water Quality Due to UV/H ₂ O ₂ Treatment..... 20
2.4.3.4	Cost 20
2.4.4	Cavitation Technology..... 20
2.4.4.1	Sonication 21
2.4.4.2	Hydrodynamic Cavitation 21
2.4.4.3	Treatment of MtBE Using Cavitation Technology 21
2.4.4.4	Impact of Water Quality Parameters and Co-contaminants on MtBE Treatment by Cavitation..... 22
2.4.4.5	Impact on Water Quality due to Cavitation Process..... 22
2.4.4.6	Cost 22
2.4.5	TiO ₂ – Catalyzed UV Oxidation Process 22
2.4.5.1	TiO ₂ – UV System for Treatment of MtBE in Drinking Water 23
2.4.5.2	Impact of Water Quality Characteristics on MtBE Treatment by TiO ₂ -UV Systems 23
2.4.5.3	Impact on Water Quality..... 23
2.4.5.4	Cost 23
2.4.5.5	Fenton's Reaction Process 23
2.4.5.6	Fenton Process for Treatment of MtBE 24
2.4.5.7	Impact of Water Quality Parameters on Fenton Reaction Process..... 24
2.4.5.8	Impact of Fenton Process on Water Quality 24
2.5	Biodegradation of MtBE 24
2.5.1	Cost 25
2.6	Membrane Technology..... 25
2.6.1	Impact of Water Quality Characteristics on MtBE Treatment Using Membrane..... 26
2.6.2	Impact of Membrane Treatment on Water Quality..... 26
2.6.3	Treatment Cost 26
2.7	Electron Beam Technology..... 26
2.7.1	E-Beam Technology for MtBE Removal..... 27
2.7.2	Impact of Water Quality Characteristics and Co-contaminants on E-Beam Treatment 27
2.7.3	Effect of E-beam treatment on Treated Water Quality 28
2.7.4	Cost 28
2.8	Blending 28

TABLE OF CONTENTS (continued)

<u>SECTION</u>	<u>PAGE</u>
3 GAC TREATMENT TECHNOLOGY STUDIES	29
3.1 Summary of GAC Bench Studies.....	29
3.1.1 UCLA Charnock Well Field Isotherm Studies	29
3.1.2 Calgon Isotherm Studies.....	30
3.1.3 tBA Isotherm Studies	30
3.1.4 Charnock Well 19 ACT Studies	30
3.1.5 Shell Abrams Isotherm Studies	30
3.1.6 Shell Abrams ACT Studies.....	30
3.1.7 Arcadia ACT Studies.....	31
3.2 Summary of GAC Pilot Studies.....	31
3.2.1 Fate of Iron and Manganese	31
3.2.2 Fate of MtBE in the Columns:	32
3.2.3 tBA in Non-acclimated GAC	32
3.2.4 tBA in Acclimated GAC	32
3.2.5 TOC	32
3.2.6 DO Concentration in the Columns.....	32
3.2.7 The Distribution of the Heterotrophic Bacterial Counts along the Carbon Bed.....	33
3.3 GAC Test Problems and Solutions	33
4 ADSORPTIVE RESIN TREATMENT TECHNOLOGY	34
4.1 Summary of Isotherm Bench Studies.....	34
4.1.1 Equilon Bench Studies	34
4.1.2 UCLA Bench Studies	34
4.2 Summary of Adsorptive Resin Bench Column Studies.....	35
4.3 Summary of Adsorptive Resin Pilot Studies.....	36
4.4 Adsorptive Resin Test Problems and Solutions	36
5 AIR STRIPPING TREATMENT TECHNOLOGY STUDIES.....	37
5.1 Summary of Bench-Scale Studies	37
5.2 Summary of Pilot Air Stripping Study (Shell Abrams site)	37
5.2.1 Pilot Air Stripper System Description.....	37
5.2.2 MtBE Removal Performance.....	38
5.2.3 TPH-G and BTEX Removal Performance	38
5.2.4 tBA Removal Performance.....	38
5.2.5 Off-Gas Treatment Performance	38
5.3 Summary of Full-Scale Air Stripping Performance Tests	38
5.3.1 Full-Scale Air Stripper System Description.....	38
5.3.2 MtBE Removal Performance.....	39
5.3.3 TPH-G and BTEX Removal Performance	39
5.3.4 tBA Removal Performance.....	39
5.3.5 RTO Performance.....	39
5.4 Air Stripping Test Problems and Solutions.....	40
5.4.1 Air Stripper Packing Fouling.....	40

TABLE OF CONTENTS (continued)

<u>SECTION</u>	<u>PAGE</u>
5.4.2 Off-Gas Emission Permitting	40
6 AOP TREATMENT TECHNOLOGY STUDIES	41
6.1 Summary of AOP Pilot Studies	42
6.1.1 Remediation Application-Wayne Perry UV/H ₂ O ₂	42
6.1.2 Remediation Application-Wayne Perry O ₃ /H ₂ O ₂	42
6.1.3 Drinking Water Application-Kennedy/Jenks UV/H ₂ O ₂	42
6.1.4 Drinking Water Application-Kennedy/Jenks O ₃ /H ₂ O ₂	46
6.1.5 Drinking Water Application-MWD O ₃ /H ₂ O ₂	47
6.1.6 Full Scale UV/H ₂ O ₂ Remediation Evaluation-Shell Abrams	47
6.2 AOP Test Problems and Solutions	47
6.2.1 UV/H ₂ O ₂	48
6.2.2 O ₃ /H ₂ O ₂	48
7 REPRESENTATIVE MASS BALANCES	49
7.1 Drinking Water Applications	49
7.1.1 GAC-Drinking Water Application	49
7.1.2 Adsorptive Resin-Drinking Water Application	50
7.1.3 Air Stripper-Drinking Water Application	50
7.1.4 Advanced Oxidation Process-Drinking Water Application	51
7.2 Remediation Applications	51
7.2.1 GAC-Remediation Application	51
7.2.2 Adsorptive Resin-Remediation Application	51
7.2.3 Air Stripper – Remediation Application	52
7.2.4 Advanced Oxidation Process – Remediation Application	52
8 REFERENCES	53

TABLE OF CONTENTS (continued)

LIST OF TABLES

<u>TABLE</u>	<u>TITLE</u>
--------------	--------------

VOLUME I

1	Influent Water Characteristics
2	Pilot and Bench-scale Studies Treatment Goals
3	Summary of GAC Testing
4	Summary of Carbon Usage Rates from Various Studies
5	Operational Parameters For the Kennedy/Jenks BioGAC Treatment Study
6	Projected Effluent Quality From Unit Process of a Full-Scale Plant Without tBA Pretreatment

TABLE OF CONTENTS (continued)

LIST OF FIGURES

<u>FIGURE</u>	<u>TITLE</u>
VOLUME I	
1	Acclimation Study, Pilot GAC Schematic and Sampling Locations from <i>Fate of tBA in the BioGAC</i> by Dr. P.T. Sun (Kennedy/Jenks BioGAC Pilot Study)
2	MtBE Breakthrough Curves from <i>Fate of tBA in the BioGAC</i> by Dr. P.T. Sun (Kennedy/Jenks BioGAC Pilot Study)
3	tBA Breakthrough Curves from <i>Fate of tBA in the BioGAC</i> by Dr. P.T. Sun (Kennedy/Jenks BioGAC Pilot Study)
4	tBA-Biodegradation Inside the Carbon Column from <i>Fate of tBA in the BioGAC</i> by Dr. P.T. Sun (Kennedy/Jenks BioGAC Pilot Study)
5	Dissolved Oxygen Concentration Inside the Carbon Column from <i>Fate of tBA in the BioGAC</i> by Dr. P.T. Sun (Kennedy/Jenks BioGAC Pilot Study)
6	Heterotrophic Plate Counts Inside the Carbon Column from <i>Fate of tBA in the BioGAC</i> by Dr. P.T. Sun (Kennedy/Jenks BioGAC Pilot Study)
7	Adsorption Isotherms for MtBE, tBA, Acetone – Ambersorb 563
8	Adsorption Isotherms for MtBE – Synthetic Groundwater GAC, Ambersorb 563, DOWEX OPTIPORE L493
9	Ambersorb 563 Column Run 3.1
10	Run 3.1 Steam Regeneration of Ambersorb 563
11	MtBE EE/O as a Function of Inlet MtBE with and without tBA, Kennedy/Jenks UV/H ₂ O ₂ Pilot Study
12	Block Flow Diagram/Sample Mass Balance, Drinking Water Application – Primary Treatment – GAC
13	Block Flow Diagram/Sample Mass Balance, Drinking Water Application – Primary Treatment – Adsorptive Resin
14	Block Flow Diagram/Sample Mass Balance, Drinking Water Application – Primary Treatment – Air Stripper
15	Block Flow Diagram/Sample Mass Balance, Drinking Water Application – Primary Treatment – AOP
16	Block Flow Diagram/Sample Mass Balance, Remediation Application – Primary Treatment – GAC
17	Block Flow Diagram/Sample Mass Balance, Remediation Application – Primary Treatment - Adsorptive Resin
18	Block Flow Diagram/Sample Mass Balance, Remediation Application – Primary Treatment – Air Stripper
19	Block Flow Diagram/Sample Mass Balance, Remediation Application – Primary Treatment - AOP

TABLE OF CONTENTS (continued)

LIST OF APPENDICES

APPENDIX TITLE

VOLUME I

- A GAC Treatment Technology Studies
- B “Activated Carbon Test Results for the Charnock Site” Presentation (Calgon Carbon Corp.)
- C GAC Study (US Filter)
- D ACT (Komex)
- E BioGAC (Paul Sun)
- F Wayne Perry Studies at Site 11, Abrams Shell (Wayne Perry, Inc.)
- G “Treatability of Groundwater Containing MtBE by Ozone and Peroxone and Identification of By-Products” (Sun Liang)
- H O₃-H₂O₂ Report (Applied Process Technology)
- I Confidential Test Report on the UV Oxidation Design Test to Treat Groundwater from the Charnock Well Field (Calgon Carbon Corp.)

VOLUME II

- J Pilot Study – UV/H₂O₂ Oxidation Process, City of Santa Monica Charnock Well Field (Kennedy/Jenks Consultants)

VOLUME III

- J Continuation of Appendix J: Appendices to the Pilot Study – UV/H₂O₂ Oxidation Process, City of Santa Monica Charnock Well Field (Kennedy/Jenks Consultants)

VOLUME IV

- K Resin Isotherms (Paul Sun)
- L Column Studies (Paul Sun)
- M GAC Studies (UCLA, Mel Suffet)

1 INTRODUCTION

This report has been prepared by Kennedy/Jenks Consultants (Kennedy/Jenks) on behalf of Shell Oil Company (Shell), Shell Oil Products Company, and Equilon Enterprises LLC (Equilon) as required by joint agency requirements contained in Attachment A, Scope of Work (SOW), Task 5, to the Los Angeles Regional Water Quality Control Board (LA RWQCB) Stipulated Agreement No. 00-064 and the United States Environmental Protection Agency (USEPA) Administrative Order on Consent USEPA Docket No. RCRA 7003-09-2000-0003 (SA/AOC).

Task 5 is entitled "Completion of Treatability Technology Performance Report." The purpose of this task is to provide the information necessary to evaluate the ability of various treatment technologies to effectively remove Methyl *tertiary* Butyl Ether (MtBE), *tertiary* Butyl Alcohol (tBA) and other gasoline contamination constituents from contaminated groundwater. Four specific technologies were identified in the agency SOW for inclusion in this performance report: granular activated carbon (GAC), advanced oxidation process (AOP), resin adsorption, and air stripping.

This report includes data generated during the Charnock Well Field Startup LLC treatability studies, the potentially responsible party (PRP) Site 11 (Abrams Shell) studies, and other bench-scale or pilot studies conducted using Charnock Sub-Basin water. A literature review and summary of relevant information regarding the treatment of oxygenates in drinking water were also completed. Finally, preliminary mass balances were estimated for the identified technologies.

1.1 Influent Water Characterization

The influent water characteristics for the pilot tests and bench-scale studies conducted for the Charnock Sub-Basin vary depending on the source water. The following three distinct water sources were identified and included in the data presented in this report:

- City of Santa Monica (COSM) Charnock Well Field.
- COSM Arcadia Well Field.
- Upper groundwater aquifer at Abrams Shell Site 11.

Table 1 presents the water influent characteristics for the three water sources.

The concentration levels and range of constituents produced from the shallow aquifer groundwater at the Abrams Shell site differ greatly from the profile of the groundwater produced from the deeper aquifers. Generally, the Abrams Shell site contains a wider array of fuel contaminants, and these contaminants are present at higher concentrations.

A further discussion of the Charnock Sub-Basin groundwater characteristics will be included in the submittal for Task 4 for the joint agency SOW.

1.2 Treatment Goal Basis

Pilot and bench study work was accomplished by a number of different parties. The following describes the various studies and their treatment goals, if applicable.

1.2.1 Drinking Water

Several studies have been conducted using Charnock Sub-Basin groundwater to assess treatment of MtBE. Because the objectives and conditions of many of these studies varied, the data for the studies cannot always be correlated directly. The treatment goals for several studies are presented in Table 2.

1.2.2 Discharge to NPDES Connector

The Abrams Shell Site 11 remediation project discharges treated water under NPDES Permit No. CA0064289. The established maximum values or ranges are as follows:

- TPHg – 100 µg/l
- Benzene – 1 µg/l
- Toluene – 150 µg/l
- Ethylbenzene – 700 µg/l
- Xylenes – 1,750 µg/l
- MtBE – 13 µg/l
- tBA – 1,750 µg/l
- pH – 6.0-9.0

1.3 Report Organization

The information in this report is presented in the following order:

- Section 1: introduction and approach of the study
- Section 2: literature review
- Section 3: GAC technology study results
- Section 4: adsorptive resin treatment technology results
- Section 5: air stripping treatment technology study results
- Section 6: AOP treatment technology study results
- Section 7: representative block flow diagrams and mass balance results
- Section 8: references for this report
- Appendices A through M: bench-scale and pilot study reports relevant to the Charnock Sub-Basin groundwater.